

U.S. PATENT APPLICATION

OF

Robert S. WHITEHOUSE, Sean DAUGHTRY, and  
Luhua ZHONG

FOR

POLYURETHANES OBTAINED FROM HYDROXYALKANOATES AND ISOCYANATES

0005156-071301  
F00T20-95T50660

## POLYURETHANES OBTAINED FROM HYDROXYALKANOATES AND ISOCYANATES

This application claims the benefit under 35 U.S.C. § 119(e) of prior U.S. Provisional  
5 Patent Application Nos. 60/218,384 filed July 14, 2000 and 60/225,902 filed August 17, 2000,  
which are incorporated in their entirety by reference herein.

### **BACKGROUND OF THE INVENTION**

The present invention relates to polyurethanes and to products containing or formed from  
polyurethanes, such as foams, elastomers, adhesives, coatings, textiles, and the like.

10 In general, the raw materials for preparing polyurethanes are polyisocyanates, polyols,  
diamines, catalysts, additives, and blocking agents. The polyisocyanates are either aliphatic, like  
hexamethylene diisocyanates, isophorone diisocyanate, and 4,4'-diisocyanate dicyclo  
hexylmethane, or the polyisocyanates can be aromatic, like 2,4-toluene diisocyanate, 1,5-  
naphthalene diisocyanate, and 4,4'-methylene diphenyl diisocyanate. The polyols are typically  
15 polyethers, such as propylene glycol and trimethylolpropane combined with sucrose or polyesters,  
or ethylene glycol, 1,2-propanediol, 1,4-butanediol, and diethylene glycol combined with glycerol.  
Polyethers are typically used to produce flexible and rigid foams and polyesters are typically used  
to produce elastomers, flexible foams, and coatings. Lewis acids and Lewis bases are typically used  
as catalysts. Additives, which can be present, are typically polysiloxane-polyether, carbodiimide  
20 piperazine, chloro-fluoro-hydrocarbons, and phosphorous and nitrogen containing compounds.

U.S. Patent No. 4,324,880 to Dhein et al. describes the formation of a lacquer from the  
transesterification reaction of PHB with a polyhydroxycompound such a trimethylol propane or  
pentaerythritol in the presence of dibutyl tin oxide to produce a reaction product having a  
hydroxyl number between 50 and 400. No description of the reaction product is given.  
25 However, because an excess of PHB was used relative to the polyhydroxycompound, one would  
expect that the resultant product is predominantly the n-ester, where n is the number of hydroxyl

groups present in the polyhydroxy compound. Because the reaction product is ill defined one could expect significant variability in the final lacquer product.

U.S. Patent No. 5,352,763 to Yamaguchi et al. describes the formation of an oligomer having the general structure  $(ABA)_n X$  where A is a polyhydroxyalkanoate oligomer and B is a difunctional coupling agent and X is a di-isocyanate compound. Reaction conditions are similar to those described in U.S. Patent No. 4,324,880 with the reactants being the alkylester of the (R) 3- hydroxyalkanoate and a smaller molar contribution of the diol "B" coupling agent.

U.S. Patent No. 5,665,831 to Neuenschwander et al. describes biodegradable block copolymers containing two distinct copolymer blocks. One of the copolymer blocks is obtained from the transesterification of poly (R ) 3 hydroxybutyrate (or poly (R ) 3 hydroxybutyrate co (R ) 3 hydroxyvalerate ) with ethylene glycol using similar reaction conditions described in U.S. Patent Nos. 4,324,880 and 5,352,763.

In all three patents, the descriptions indicate that the resulting diol ester contains terminal secondary hydroxyl groups on the chiral carbon atoms from the (R ) hydroxyalkanoate moiety. Because both terminal hydroxyl groups have the same reactivity, i.e., secondary hydroxyl group, then subsequent reactions with for instance, an isocyanate group will occur with equal frequency at both ends of the oligomer.

In the present invention, the hydroxyl terminated hydroxyalkanoate derivatives preferably have hydroxyl terminal groups with different functionalities. This significantly changes the subsequent reaction methodology when combined with polyisocyanate molecules to form polyurethanes. By modifying the reaction conditions, the present invention generates unique polyurethane structures with enhanced physical properties.

While there are a variety of polyurethanes available, there is a need to form polyurethanes which have the capability of being biodegradable or can be easily recycled. In addition, there is a

need to provide polyurethanes which preferably have improved flexibility and/or improved hydrophobicity.

#### **SUMMARY OF THE PRESENT INVENTION**

5 A feature of the present invention is to provide polyurethanes which are biodegradable.

Another feature of the present invention is to provide polyurethanes which can be recycled.

A further feature of the present invention is to provide polyurethanes having improved physical properties, such as improved flexibility and/or improved hydrophobicity.

10 Additional features and advantages of the present invention will be set forth in part in the description which follows, and in part will be apparent from the description, or may be learned by practice of the present invention. The objectives and other advantages of the present invention will be realized and obtained by means of the elements and combinations particularly pointed out in the written description and appended claims.

15 To achieve these and other advantages, and in accordance with the purposes of the present invention, as embodied and broadly described herein, the present invention relates to a polyurethane obtained by the reaction of at least one isocyanate containing material and at least one compound having at least two hydrogen atoms and capable of reacting with isocyanate groups, such as a hydroxyl-containing material, wherein the compound contains a thermally decomposable or a biodegradable hydroxyalkanoate. The hydroxyl-containing material preferably has hydroxyl  
20 terminal groups with different functionalities.

The present invention further relates to foams, elastomers, coatings, adhesives, and textiles containing the above-described polyurethane.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are intended to provide a further explanation  
25 of the present invention, as claimed.

## DETAILED DESCRIPTION OF THE PRESENT INVENTION

The present invention relates to polyurethanes and products made from or containing polyurethanes. The present invention also relates to methods of making polyurethanes.

5 For purposes of the present invention, the polyurethane can be a polyurethane obtained by the reaction of a) at least one isocyanate containing material and b) at least one compound containing at least two hydrogen atoms and capable of reacting with isocyanate groups. The compound containing at least two hydrogen atoms contains, as part of the compound, a biodegradable or a thermally decomposable hydroxyalkanoate. As a result, the polyurethane is  
10 preferably at least partially biodegradable and/or thermally decomposable.

For purposes of the present invention, the polyurethane of the present invention can be linear or cross-linked. The polyurethane can be any type of polyurethane such as, but not limited to, castable, millable, thermoplastic, cellular, sprayable, poromeric (e.g., porous), fibrous, and the like. These various types of polyurethanes can be formed using the components of the present invention  
15 along with the knowledge of those skilled in the art with respect to making these particular types of polyurethanes. For instance, a linear polyurethane is typically prepared by reacting a hydroxyl-containing group with an aliphatic diisocyanate. Castable polyurethanes are typically obtained by extending hydroxyl-containing compounds with diisocyanate to yield an isocyanate-terminated prepolymer. Glycol or diamine chain extenders can then be used to bring about further chain  
20 extension. Typically, a slight excess of diisocyanate is normally employed and this enables the crosslinking to occur at the urethane or urea group.

The molecular weight of the polyurethane can be any molecular weight and depends upon the products used to form the polyurethane. Strictly as an example, the molecular weight of the polyurethane can be from about 20,000 to about 200,000. Other molecular weight ranges can be  
25 obtained.

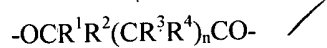
The isocyanate containing material can typically be a polyisocyanate. Preferably, the isocyanate containing material contains at least two isocyanate groups per molecule. The polyisocyanates can be any polyisocyanate traditionally used in the formation of polyurethanes. These polyisocyanates can be modified or unmodified versions. Preferably, the polyisocyanate is an aromatic polyisocyanate. A more specific example would be a toluene diisocyanate or mixtures containing toluene diisocyanate. The isocyanates can also be modified by other components, such as urethane, allophanate, uretdione, or other groups. The isocyanates described earlier can also be used. The isocyanate component is preferably a toluene diisocyanate, methylene 4,4' diphenyl diisocyanate, isophorone diisocyanate, hexamethylene diisocyanate, or combinations thereof. Generally, the amount of isocyanate used would be the same as in the conventional making of polyurethanes. Examples of amounts are from about 5 to about 50% by weight of total reactants.

With respect to the compound containing at least two hydrogen atoms and also containing a thermally decomposable or a biodegradable hydroxyalkanoate, this compound is capable of reacting with an isocyanate. Thermally decomposable includes the property wherein the hydroxyalkanoate breaks down molecularly at temperatures of about 200°C or higher. Preferably, the compound is a hydroxyl-containing material having at least two hydroxyl groups. More preferably, the compound is a polyol compound such as 4 hydroxy butyl (3 hydroxybutyrate) and butyl bis (3 hydroxyoctanoate). As indicated, the compound which reacts with the isocyanate has a hydroxyalkanoate as part of the compound. Preferably, from about 5% to about 100% by weight of the compound contains the hydroxyalkanoate, which is preferably a polyhydroxyalkanoate. The polyhydroxyalkanoate can be synthetic or prepared by other means, such as by biosynthesis. Biosynthesis methods are preferred due to the product having chiral(s).

Several types of polyhydroxyalkanoates (PHAs) are known. It is useful to broadly divide the PHAs into two groups according to the length of their side chains and according to their pathways for biosynthesis. Those with short side chains, such as polyhydroxybutyrate (PHB), a

homopolymer of R-3-hydroxybutyric acid units, are crystalline thermoplastics; PHAs with long side chains are more elastomeric. The former polymers have been known for about seventy years (Lemoigne & Roukhelman 1925), while the latter polymers are a relatively recent discovery (deSmet, *et al.*, *J. Bacteriol.*, **154**:870-78 (1983)). Before this designation, however, PHAs of microbial origin containing both R-3-hydroxybutyric acid units and longer side chain units from C5 to C16 were identified (Wallen & Rowhder, *Environ. Sci. Technol.*, **8**:576-79 (1974)). A number of bacteria which produce copolymers of D-3-hydroxybutyric acid and one or more long side chain hydroxyacid units containing from five to sixteen carbon atoms have been identified more recently (Steinbuechel & Wiese, *Appl. Microbiol. Biotechnol.*, **37**:691-97 (1992); Valentin *et al.*, *Appl. Microbiol. Biotechnol.*, **36**: 507-14 (1992); Valentin *et al.*, *Appl. Microbiol. Biotechnol.*, **40**:710-16 (1994); Abe *et al.*, *Int. J. Biol. Macromol.*, **16**:115-19 (1994); Lee *et al.*, *Appl. Microbiol. Biotechnol.*, **42**:901-09 (1995); Kato *et al.*, *Appl. Microbiol. Biotechnol.*, **45**:363-70 (1996); Valentin *et al.*, *Appl. Microbiol. Biotechnol.*, **46**:261-67 (1996); U.S. Patent No. 4,876,331 to Doi). Useful examples of specific two-component copolymers include PHB-co-3-hydroxyhexanoate (Brandl *et al.*, *Int. J. Biol. Macromol.*, **11**:49-55 (1989); Amos & McInerney, *Arch. Microbiol.*, **155**:103-06 (1991); U.S. Patent No. 5,292,860 to Shiotani *et al.*). Chemical synthetic methods have also been applied to prepare racemic PHB copolymers of this type for applications testing (WO 95/20614, WO 95/20615, and WO 96/20621).

For purposes of the present invention, the molecular weight of the PHAs is from about 100 to about 2 million Daltons, and more preferably from about 500 to about 750,000 Daltons. The PHAs can contain one or more units of the following formula:



wherein n is 0 or an integer of from 1 to 20,000 or more; and wherein R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, and/or R<sup>4</sup> are independently selected from saturated and unsaturated hydrocarbon radicals, halo- and hydroxy- substituted radicals, hydroxy radicals, halogen radicals, nitrogen-substituted radicals, oxygen-substituted radicals, and hydrogen atoms.

Preferably n is from 0 to 5 and more preferably from 1 to about 3. Examples of R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup> and/or R<sup>4</sup> include, but are not limited to, hydrogen, methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, and the like.

Suitable monomeric units include hydroxybutyrate, hydroxyvalerate, hydroxyhexanoate, hydroxyheptanoate, hydroxyoctanoate, hydroxynonanoate, hydroxydecanoate, hydroxyundecanoate, and hydroxydodecanoate units. PHAs, including monomers and polymers and derivatives of 2-hydroxyacids, 3-hydroxyacids, 4-hydroxyacids, 5-hydroxyacids, p-lactic acid, and p-glycolic acid, can be used. Representative PHAs are described in Steinbüchel & Valentin, *FEMS Microbiol. Lett.*, **128**:219-28 (1995).

Preferred PHAs include, but are not limited to, homopolymers of PHAs, polyhydroxybutyrate; a copolymer of hydroxybutyric acid and hydroxyvaleric acid (e.g., a copolymer of 60-99 weight % hydroxy butyric acid and 1-40 weight % hydroxyvaleric acid); a copolymer of 3-hydroxybutyric acid and 4-hydroxybutyric acid; polyhydroxyoctanoate; a copolymer of 4-hydroxybutyric and 4-hydroxyhexanoic acid; a copolymer of 4-hydroxybutyric acid and 4-hydroxyoctanoic acid; a copolymer of 3-hydroxyoctanoic acid with 3-hydroxybutyric acid; a copolymer of 3-hydroxyhexanoic acid and 3-hydroxybutyric acid; a copolymer containing hydroxyoctonate groups randomly distributed through the polymer chain (e.g., at least 10% by molar mass hydroxyoctanoate groups randomly distributed through the polymer chain of a copolymer); and combinations thereof. The polyhydroxyalkanoate can also have end chain functionalities such as groups selected from vinyl; carboxylic acid; carboxylic acid ester; acetate; butyrate; propanoate; primary, secondary, or tertiary alcohol; amide; and/or a polyhydric alcohol.

The PHA can also have the formula  $RCH=CH_2(CH_2)_{n-1}CO[OCHR(CH_2)_nCO]_pOH$ . Alternatively, the PHA can have the formula  $H[OCHR(CH_2)_nCO]_pOR'$ . Further, the PHA can have the formula  $R''CO[OCHR(CH_2)_nCO]_pOH$ . The PHA can also be a block polymer



containing polyhydroxyalkanoate segments and at least one polyalkylene glycol segment. Preferably, for such a PHA, the block polymer preferably contains at least 20 weight % of a PHA segment and at least one polyalkylene glycol segment selected from one or more repeat units of ethylene oxide, propylene oxide, butylene oxide, or mixtures thereof. In the above  
5 formulas, p is from 1 to 1000, more preferably 2 to 1000 or 5 to 1000, R is H, CH<sub>3</sub>, C<sub>2</sub>H<sub>5</sub>, or is C<sub>3</sub>H<sub>7</sub>, C<sub>4</sub>H<sub>9</sub>, C<sub>5</sub>H<sub>7</sub>, R' is Methyl-styryl, and R'' is methyl-styryl.

The PHAs can be prepared from a biological source such as a microorganism which naturally produces the PHAs or which can be induced to produce the PHAs by manipulation of culture conditions and feedstocks, or microorganisms or a higher organism such as a plant,  
10 which has been genetically engineered so that it produces PHAs.

Methods which can be used for producing PHA polymers from microorganisms which naturally produce polyhydroxyalkanoates are described in U.S. Patent No. 4,910,145 to Holmes, et al.; Byrom, "Miscellaneous Biomaterials" in *Biomaterials* (Byrom, ed.) pp. 333-59 (MacMillan Publishers, London 1991); Hocking and Marchessault, "Biopolyesters" in *Chemistry*  
15 *and Technology of Biodegradable Polymers* (Griffin, ed.) pp. 48-96 (Chapman & Hall, London 1994); Holmes, "Biologically Produced (R)-3-hydroxyalkanoate Polymers and Copolymers" in *Developments in Crystalline Polymers* (Bassett, ed.) vol. 2, pp. 1-65 (Elsevier, London 1988); Lafferty et al., "Microbial Production of Poly-b-hydroxybutyric acid" in *Biotechnology* (Rehm & Reed, eds.) vol. 66, pp. 135-76 (Verlagsgesellschaft, Weinheim 1988); Müller & Seebach,  
20 *Angew. Chem. Int. Ed. Engl.* **32**:477-502 (1993). All patents, patent applications, and publications mentioned here and throughout this application are incorporated herein in their entirety by reference.

Methods for producing PHAs in natural or genetically engineered organisms are described by Steinbüchel, "Polyhydroxyalkanoic Acids" in *Biomaterials* (Byrom, ed.) pp.  
25 123-213 (MacMillan Publishers, London 1991); Williams & Peoples, *CHEMTECH*, **26**:38-44

(1996); Steinbüchel & Wiese, *Appl. Microbiol. Biotechnol.*, **37**:691-97 (1992); U.S. Patent Nos. 5,245,023; 5,250,430; 5,480,794; 5,512,669; 5,534,432 to Peoples and Sinskey; Agostini *et al.*, *Polym. Sci., Part A-1*, **9**:2775-87 (1971); Gross *et al.*, *Macromolecules*, **21**:2657-68 (1988); Dubois, *et al.*, *Macromolecules*, **26**:4407-12 (1993); Le Borgne & Spassky, *Polymer*, **30**:2312-19 (1989); Tanahashi & Doi, *Macromolecules*, **24**:5732-33 (1991); Hori *et al.*, *Macromolecules*, **26**:4388-90 (1993); Kemnitzer *et al.*, *Macromolecules*, **26**:1221-29 (1993); Hori *et al.*, *Macromolecules*, **26**:5533-34 (1993); Hocking & Marchessault, *Polym. Bull.*, **30**:163-70 (1993); Xie *et al.*, *Macromolecules*, **30**:6997-98 (1997); and U.S. Patent No. 5,563,239 to Hubbs *et al.* Other polymer synthesis approaches including direct condensation and ring-opening polymerization of the corresponding lactones are described in Jesudason & Marchessault, *Macromolecules* **27**:2595-602 (1994); U.S. Patent No. 5,286,842 to Kimura; U.S. Patent No. 5,563,239 to Hubbs *et al.*; U.S. Patent No. 5,516,883 to Hori *et al.*; U.S. Patent No. 5,461,139 to Gonda *et al.*; and Canadian Patent Application No. 2,006,508. WO 95/15260 describes the manufacture of PHBV films, and U.S. Patent Nos. 4,826,493 and 4,880,592 to Martini *et al.* describe the manufacture of PHB and PHBV films. U.S. Patent No. 5,292,860 to Shiotani *et al.* describes the manufacture of the PHA copolymer poly(3-hydroxybutyrate-co-3-hydroxyhexanoate).

Preferably, the hydroxyalkanoate which forms part of the compound has one of the following formulas:

- a)  $\text{HOCHR}(\text{CH}_2)_y\text{COO A OH}$  wherein R is hydrogen, a saturated alkyl group having from 1 to 16 carbon atoms or an unsaturated alkyl group having from 2 to 16 carbon atoms or mixtures thereof. A is  $(\text{CH}_2)_n$  where n is 2 to 6 or A is  $(\text{CH}_2\text{CHR}'\text{O})_m$  where R' is hydrogen or methyl, m is from 1 to 50 and y is 0 to 3;
- b)  $\text{H}\{\text{OCHR}(\text{CH}_2)_y\text{CO}\}_x\text{O A OH}$  wherein R is hydrogen, a saturated alkyl group having from 1 to 16 carbon atoms or an unsaturated alkyl group having from 2 to 16 carbon atoms or mixtures thereof. A is  $(\text{CH}_2)_n$  wherein n is 2 to 6 or A is  $(\text{CH}_2\text{CHR}'\text{O})_m$  where R' is hydrogen or methyl, m is from 1 to 50, y is 0 to 3, and x is 2 to 1000;

- 5
- c)  $\text{HOCHR}(\text{CH}_2)_y\text{COO A OOC}(\text{CH}_2)_y\text{CHROH}$  wherein R is hydrogen, a saturated alkyl group having from 1 to 16 carbon atoms or an unsaturated alkyl group having from 2 to 16 carbon atoms or mixtures thereof. A is  $(\text{CH}_2)_n$  where n is 2 to 6 or A is  $(\text{CH}_2\text{CHR}'\text{O})_m$  where R' is hydrogen or methyl, m is from 1 to 50, and y is 0 to 3;
- 10
- d)  $\text{H}\{\text{OCHR}(\text{CH}_2)_y\text{CO}\}_x \text{ O A O } \{\text{OC}(\text{CH}_2)_y\text{CHRO}\}_x\text{H}$  wherein R is hydrogen, a saturated alkyl group having from 1 to 16 carbon atoms or an unsaturated alkyl group having from 2 to 16 carbon atoms or mixtures thereof. A is  $(\text{CH}_2)_n$  where n is 2 to 6 or A is  $(\text{CH}_2\text{CHR}'\text{O})_m$  where R' is hydrogen or methyl, m is from 1 to 50, y is 0 to 3, and x is 2 to 1000;
- 15
- e)  $\{\text{HOCHR}(\text{CH}_2)_y\text{CO}\}_z \text{ B}$  wherein R is hydrogen, a saturated alkyl group having from 1 to 16 carbon atoms or an unsaturated alkyl group having from 2 to 16 carbon atoms or mixtures thereof, y is 0 to 3 and B is selected from:
- trimethylol propane and z is 1, 2 or a mixture of 1 and 2;
  - glycerol where z is 1, 2 or a mixture of 1 and 2;
  - triethanolamine where z is 1, 2 or a mixture of 1 and 2; or
  - sucrose where z is 1 to (p-1) wherein p is the number of free hydroxyl groups
- 20
- or derivatives on the compound containing at least two hydrogen atoms; and/or
- f)  $[\text{H}\{\text{OCHR}(\text{CH}_2)_y\text{CO}\}_x]_z \text{ B}$  wherein R is hydrogen, a saturated alkyl group having from 1 to 16 carbon atoms or an unsaturated alkyl group having from 2 to 16 carbon atoms or mixtures thereof, y is 0 to 3, and x is 2 to 1000. B is selected from:
- 25
- trimethylol propane and z is 1, 2 or a mixture of 1 and 2;
  - glycerol where z is 1, 2 or a mixture of 1 and 2;
  - triethanolamine where z is 1, 2 or a mixture of 1 and 2; or
  - sucrose where z is 1 to (p-1) wherein p is the number of free hydroxyl groups
- 30
- or derivatives on the compound containing at least two hydrogen atoms.

The numbers above for x, m, n, p, y, z are integers. When there is more than one R or other variable present in a formula, the R or variable can be the same or different. Preferably, the

hydroxyalkanoate is a 3 hydroxy butyric acid combined with ethylene glycol, 1,3 propane diol, 1,2 propane diol, 1,2 butane diol, 1,3 butane diol, and/or 1,4 butane diol. Alternatively, the hydroxyalkanoate can be a 3 hydroxy butyric acid combined with polyethylene glycol, for example, 1,2 propylene glycol or 1,3 propylene glycol, and preferably having from about 1 to about 100 ethylene glycol repeating units. The hydroxyalkanoate can also be a mixture of various hydroxy alkanoates such as a mixture of 3 hydroxy butyric acid and 3 hydroxy valeric acid combined with ethylene glycol, 1,3 propane diol, 1,2 propane diol, 1,2 butane diol, 1,3 butane diol, 1,4 butane diol, or propylene glycol preferably having from about 1 to about 100 ethylene glycol repeating units. The bis (hydroxy acid esters), for instance, those set forth in c) and d) above, can be formed from 2 moles of hydroxy acid reacting with one mole of diol.

Generally, the weight ratio of isocyanate to the compound having at least two hydrogen atoms is from about 0.5:1 to about 2:1.

In making the polyurethanes of the present invention, at least one catalyst is preferably used in the reaction. Conventional catalysts used for the making of polyurethanes can be used in the present invention. For instance, such catalysts include, but are not limited to, tertiary amines, such as triethylamine, dimethylcyclohexylamine, or diazobicyclo[2.2.2.]octane. Conventional amounts of catalysts can be used in the present invention.

One or more blowing agents can additionally be used in the formation of the polyurethanes, if desired. Blowing agents activated chemically or by mechanical means can be used in the present invention. Conventional blowing agents can be used, such as water and low-boiling inert liquids, such as hydrocarbons. Preferably, the blowing agent is a pentane such as a cyclopentane or can be combinations of various blowing agents. The blowing agent can be used in conventional amounts.

Other additives customary to polyurethane formulations can be used in the present invention including, but not limited to, flame retardants, foam stabilizers, fillers, antioxidants,

0005456-074304  
FOET20-95T50500

pigments, and the like. These various additives can be used in conventional amounts, if present. The reaction conditions and various components and amounts that can be present in the present invention are described in a variety of U.S. patents, including, but not limited to, U.S. Patent Nos. 6,087,466; 6,087,410; 6,043,292; 6,034,149; and 6,087,409, all of which are incorporated  
5 in their entirety by reference herein.

In making the polyurethanes of the present invention, the reactants can simply be mixed together under ambient conditions with low shear or high shear mixing. The reaction can occur in minutes or in hours depending on temperature and the optional use of catalyst.

In one embodiment, the PHA, such as poly 3-hydroxybutyrate can be reacted with polyol.  
10 Preferably, about 2 to 3 molar excess of polyol (based on the hydroxyalkonate monomer repeat unit) required to produce the monoester is used. The molar excess drives the reaction towards the monoester formation with little or no diester product.

As another example, for conversion to the diol ester from methyl 3 hydroxybutyrate, molar equivalents, (e.g., 0.98 mol% of diol) can be used to again drive the reaction to monoester  
15 formation. Accordingly, in one embodiment of the present invention, monoester formation is preferred, wherein little (e.g., less than 10% of yield and more preferably less than 5% yield or even less than 1% yield) or no diester formation occurs in the reaction product. This reaction product can then be reacted with at least one isocyanate using known conditions to form a polyurethane.

20 The polyurethane can have a number of different properties. The polyurethane can be biodegradable and can be recycled. The polyurethane can be hydrophilic or hydrophobic. Further, the polyurethane can be used in a number of applications, including, but not limited to, coatings, foams (including rigid and flexible), elastomers, dispersions, and other water dispersible applications. The polyurethane can be formed into a number of articles, such as pipes, insulation,  
25 and any other articles traditionally formed from polyurethane materials such as dash boards, other

automobile components, and the like. These various applications can be accomplished using conventional techniques known to those skilled in the art in view of the present application.

The present invention will be further clarified by the following examples, which are intended to be purely exemplary of the invention.

5 **EXAMPLES**

**Example 1: Production of mono ethylene glycol ester of (R) 3 hydroxybutyrate**  
**HO CH (CH<sub>3</sub>) CH<sub>2</sub> C(=O) CH<sub>2</sub> CH<sub>2</sub> OH**

1300 mL of Ethylene Glycol (EG) was charged in a 3 L three neck flask. 430 g of Poly-R-3-Hydroxybutyrate (P3HB) was added while stirring with an overhead stirrer. An additional 200 mL of EG was added to help wet out all the polymer. 15 mL of H<sub>2</sub>SO<sub>4</sub> conc. with 15 mL of H<sub>2</sub>O were added dropwise. The mixture was heated to 120°C with a temperature controller. The reaction was monitored by GC. The desired ester formation occurred after 120-140 hours. After the reaction was completed, the product was cooled to room temperature. The acid product was slowly neutralized with NaHCO<sub>3</sub> or Na<sub>2</sub>CO<sub>3</sub> and was filtered to remove all solids and salts. The product was then rotovapped to remove all 'lights' (dioxane). The product was then distilled to separate the product/EG azeotrope from the heavies. The product was extracted from the distillate with EtOAc and water. The product was then distilled for final purification.

**Example 2: Production of mono ethylene glycol ester of (R) 3 hydroxybutyrate**  
**HO CH (CH<sub>3</sub>) CH<sub>2</sub> C(=O) CH<sub>2</sub> CH<sub>2</sub> OH**

61g of ethylene Glycol (EG) and 101g of methyl (R) 3 hydroxybutyrate were charged in a 500ml three neck flask. 1ml of H<sub>2</sub>SO<sub>4</sub> conc. with 2ml of H<sub>2</sub>O were added dropwise. The mixture was then heated under reflux to remove methanol. The yield was 97% mono ethylene glycol ester of (R) 3 hydroxybutyrate.

**Example 3: Production of mono glycerol ester of (R) 3 hydroxybutyrate**  
**HO CH (CH<sub>3</sub>) CH<sub>2</sub> C(=O) CH<sub>2</sub> CH (OH) CH<sub>2</sub> OH**

91g of glycerol and 101g of methyl (R) 3 hydroxybutyrate were charged in a 500ml three neck flask. 1ml of H<sub>2</sub>SO<sub>4</sub> conc. with 2ml of H<sub>2</sub>O were added dropwise. The mixture was then heated under reflux to remove methanol. The yield was 98% mono glycerol of (R) 3 hydroxybutyrate.

5 **Example 4; Production of diethanolamide ester (R) 3 hydroxybutyrate**  
**HO CH (CH<sub>3</sub>) CH<sub>2</sub> CONH (CH<sub>2</sub> CH<sub>2</sub> OH)<sub>2</sub>**

78g of diethanolamide and 101g of methyl (R) 3 hydroxybutyrate were charged in a 500ml three neck flask. The mixture was then heated under reflux to remove methanol. The yield was 98% diethanolamide ester of (R) 3 hydroxybutyrate.

10 The reaction products of each of Examples 1-4 can then be reacted with a desired isocyanate(s) under conventional reaction conditions and amounts as specified above to form the polyurethanes of the present invention.

Other embodiments of the present invention will be apparent to those skilled in the art from consideration of the present specification and practice of the present invention disclosed  
15 herein. It is intended that the present specification and examples be considered as exemplary only with a true scope and spirit of the present invention being indicated by the following claims and equivalents thereof.

0905156-071301  
T02120-9515060